NWX-NASA-JPL-AUDIO-CORE

Moderator: Michael Greene
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Dr. Nick Gautier: Okay, so hello everybody I'm glad to be here to be able to talk to you about Kepler. You should be looking at the first slide, which is the Kepler mission extrasolar planets et cetera but let's switch over to the second slide now and I'll tell you something about how this talks going to go.

First I'm going to talk about the Kepler results in its search for a potentially habitable extrasolar planets but I'm going to start out by talking about how we see extrasolar planets to kind of bring everybody up to speed on that.

And then I'll talk about how we would know a habitable extrasolar planet if we saw one and a bit about how a Kepler looks for planets and then I'll discuss the Kepler results so far and finally I'll give you a status of the Kepler mission.

So let's go to Slide 3, ways to see extrasolar planets. There are two main ways, you can look at the - it's a radial velocity method where you look at the motion of the star induced by the orbit of the planet around it.

The planet - a planet and around its star are kind of balanced around a center of gravity and as the planet moves the star move too. So if you have a highly precise radial velocity measurement you can determine the motion of the star and since you know something about the mass of the star you can figure out the mass of the planet, the orbital period, the shape of the orbit and the distance of the planet from the star.

Another popular method for finding exoplanets is the transit photometry method or the star dimming method. And this works because if extrasolar planets are in orbit around stars from time to time the planet will have its orbit aligned in such a way that for part of its orbit it will pass in front of the star as seen from the earth.

And you'll get a small dimming of the star as the planet does that. It tends to be about 1% dimming for Jupiter size planets and about 1/100 of a percent dimming for Earth size planets around solar sized stars.

These dimmings only last for a number of hours, a few hours to a few tons of hours. So one has to watch these stars like a hawk in order to see the transits from periods especially long ones like a year.

The transit photometry method what you get to measure is how much of the starlight the planet blocks out. So again you know something about the star you can figure out the size of the planet, it's a little period and therefore its distance from the star.

Now down in the lower left of this chart there in blue there is some other methods for detecting extrasolar planets but they are less prolific and I am not going to talk about them tonight.

Let's go to the next Slide Number 4 and now the point about this one is that if you can measure both the mass and the size of the planet, which we can do from time to time you can tell if the planet - you can tell what the density of the planet is.

And if it's a low density planet you can figure it's mostly made out of gas, it's a gas giant. For instance you might know that the density, bulk density of Saturn is less than that of water.

Medium density planets are probably going to be made of a lot of water and ice and but many minerals and not such particularly large gas envelope. And high density planets we will assume have to be made out of rock.

So let's go to Slide 5 where we ask how would we know a habitable planet if we saw it. Let's go to Slide 6, well how would we know if we found another Earth?

Well we do that by trying to look for what we call habitable planets and I have a picture of one here illustrating what they might look like. You should now go to Slide 7.

And these habitable planets are going to have the right temperature for habitability, they're going to have liquid water on the surface and they're going to have an atmosphere that would support the - prevent the liquid water from evaporating and protect the surface of the planet from space radiation.

Now you could argue or question whether this is the only kind of planet that can be habitable but it's one kind of planet that we know is habitable because we live on an example.

And so we know that if we look for this kind of thing we're going to find something that is probably habitable and if we're looking for another Earth this is what we've got to look for.

Next slide, obviously the correct temperature and the liquid water aspects of habitable planets are kind of coupled together so we're going to talk about that a little more in a second.

Next slide, we should be on Slide Number 9 now. So planets we're finding come in several sizes. Some of them are to big, more than about 10 Earth masses to support the kind of atmosphere that we're looking for, for habitability.

These planets hold tightly onto the light gases like hydrogen and helium and turn into gas giants with deep atmospheres and probably no habitable surface. There are planets that are going to be to small less than about half the mass of the Earth that can't hold onto a life sustaining atmosphere for any length of time and examples of these would be the Moon or Mercury.

But planets with masses between about half the mass of the Earth and 10 Earth masses are not going to hold onto their light gases very well but they will hold onto the heavier gases like nitrogen and oxygen long enough to have a potentially habitable atmosphere for a long period of time perhaps long enough for life to evolve.

Next Slide Number 10, so planets also come in a range of temperatures. Ones that are very close to their star are going to be to hot for habitability, ones that are very far from their star to far from their star are going to be to cold for habitability.

But there will be a distance around each star where the planetary temperature can have an all surface temperature, which could well support liquid water if the planet has water.

Now the next slide we introduce the concept of a habitable zone. This is the region around the star where liquid water might exist on a planet surface. Some people call this the Goldilocks zone.

In this slide I've illustrated the to hot zone by the red close to the stars and the to cold zone by the blue farthest from the stars and the just right zone for habitability is the green band in between.

Now for stars hotter and more massive than the sun F stars or earlier the habitable zone is going to be characterized by orbits from about 2 years to 10 years period.

For sun like starts the orbital periods are going to be nine months to 3-1/2 years and for cooler stars less mass in the sun they might be 3 to 13 months. So these are the periods that we have to look for planets in order to find potentially habitable ones.

So when you go to look for planets either with the radial velocity method or the transit method you have to look at them for several times these orbital periods in order to make sure you've seen the correct signal and built up enough signal and noise to do the detection properly.

Now, my slide editing was a little bit poor so I'm going reorder things. I'd like you to jump ahead three slides I believe to number 14 right now. And this is the one that says radial velocity measurements are good for finding large planets.

And that's because you have to have a big planet to move the star enough to make its radial velocity variations detectable against the various noises in the measurement.

So we can find good planets around - so big planets around solar type stars, you can find Earth size planets around small cool stars but the sensitivity is not good enough to find Earths around sun like stars.

Also radial velocity detections are very slow you can only do one star at a time and well there are multiple spectrographs that can do more than one star at a time but if you're picking the stars you want they might not be close enough together to use multiple spectrographs.

When we do a small number of stars at a time and you need many measurements totaling maybe hundreds of hours of observation to get a good clean signal on the orbit you're looking for radial velocity orbit you're looking for.

Now transit searchers from the ground are good for finding lots of large planets because you can look at - with wide field telescopes you can do photometry on hundreds or thousands of stars at once and look for the few stars that are going to line up - few planets that are going to - few stars that are going to have planets that whose orbits line up properly for transit.

So you can find lots of large planets but the noise introduced by the atmosphere of the Earth and the photometry makes these - this method not good enough to find Earth sized planets around sun like stars.

So we need another way to find Earths and let's go to the next slide, which is the one that says Kepler's telescope photometer. So we built the Kepler telescope photometer to do this job of looking for Earth sized planets around sun like stars with the transit method.

So we built it with a wide field it's got a 15 diameter field of view so it can monitor 150,000 stars at once. It's big enough almost a meter across collecting area to get enough light so we can get the sensitivity in with these 150,000 stars, which are fairly dim, I'll tell you about that in a second, to resolve out the10 parts, 20 parts per million transit signals that we have to see.

And we built it for use in space so we eliminate the variability from the Earths atmosphere to mask small transits. Now to continue my on real time editing of the slides I want you to back up three slides to number 12, which says transits won't find all planets.

This is where we introduce an inconvenience with the transit method. Not all planets orbits are aligned to produce a transit. The orbit has to be quite precisely aligned so that it aligned with your line of sight so the planet does transit the surface of the star seen from Kepler in this case.

There's only a few percent of a chance for a given planet to transit. For instance the Earth and the sun have only a 1/2 percent chance of showing a transit from any given nearby star. Transits as I said only last a few hours each orbit so you must stare constantly at many thousands of stars to find very many planets.

Next Slide Number 13, there is a pitfall that we must avoid with the transit method because there are astrophysical phenomena, which can mimic transiting planet signals.

One of the principle ones would be an eclipsing binary star, which often, you know, has transit depths of 50% or 30% or something like that. Being having its light diluted by the light of the star we're trying to find planets around because the two stars the eclipsing binary and our target star are very close together on the sky.

So then the 50% or 30% transit signal from the or eclipse signal from the eclipsing binary star would be diluted by our target star so it could look at 1% or 1/10 of a percent of 1/100 of a percent deep and look like a transiting planet.

So the planets that we find - the transit signals that we find from Kepler are called candidate transiting planets at the beginning because we need to look very carefully at these candidates in order to week out the false positives and make sure we have a relatively pure sample of real planets.

And the Kepler follow up program ground based and otherwise and other parts based on the Kepler data does this and I'll discuss how good this is in a little bit.

Now skip ahead three more slides to number 16 where I show a little bit - I'm going to start to talk a little bit about how Kepler actually works. This is the Kepler field of view on the sky.

It's just a little bit North of the galactic plane on the constellation of Cygnus. And that peculiar pattern you see there is the actual projection of the CCD's in our focal plane on the sky.

We have 21 modules, a 5 by 5 square with the corners missing and each module has a 2K by 1K CCD in it. We picked this spot because we needed a - an area with lots of stars so it had to be near the plane of the galaxy.

But it can't have to many stars in it otherwise the stars get confused with each other because we have relatively large pixels for arc seconds. So it has to be a little bit off the plane of the galaxy in sort of a sweet spot for stellar density.

But it also has to be in a spot in the sky that's as far as we can get from the ecliptic plane so that in the season when the sun is nearby the Kepler can have a sun shade that's large enough to prevent sunlight from falling in the telescope.

So there are two spots in the sky where this occurs. One of them is in Cygnus in the North where the galactic plane has its maximum separation from the ecliptic plane and the other is a similar spot in the South in which constellation I don't remember.

We picked the spot in the North because we wanted to do the follow up of Kepler candidates with Northern hemisphere telescopes. Next Slide Number 17.

Here we've taken the data from a full focal plane of Kepler, every pixel and put the pixels on the sky in their correct locations. So you can see what the Kepler field of view looks like.

You can see the separations between the CCD's and the picture of the full moon there is for scale. The field of view is about 15 degrees across corner to corner.

Now it doesn't look very good because there's all these dark lines in it but we're not looking for a pretty picture we're looking for sky acreage so we can get many, many stars.

And in fact we used these wide half degree dark lines between the modules to hide some of the bright stars in that part of Cygnus that are to bright for Kepler to look at.

Next Slide Number 18, this is the sort of the Kepler search space shown in this artists conception of what the Milky Way looks like. We're looking down a cone something like 3000 light years long down the local spur of the galaxy.

And the distance at which we can see the stars is determined by the or the distance over which we search is determined by the dynamic range of Kepler. We can only effectively do our precision photometry on stars between about 10th magnitude and 15th magnitude.

Although we can do brighter stars but it stresses the Kepler system. So for nearby M stars, nearby bright M stars we're going to see the closest part of our search column a few tens of light years away. And for the brightest stars that we look at they can go out to 3 or even 6000 light years at 15th magnitude. We restricted our target sample to F, G and K - F, G, K and M stars and dwarfs because giant stars and earlier type stars that are larger we cannot see Earth like - Earth size transiting planets around because the transit signal is to small, the star diameter is to large. So basically we're searching the extended solar neighborhood for planets.

Next Slide Number 19, and here I'm beginning to show some of the Kepler results. These planet candidates as of the beginning of 2011 were the first batch of candidates that we produced.

And here I plotted them in this chart where we show the orbital period and days along the bottom and the size relative to Earth along the side. And I marked lines for several familiar solar system objects to give you an idea of the size.

At the time we had about 1200 candidates and they point out that these are the planet candidates and they have a certain amount of false positives left in them because they haven't - every one of these hadn't been completely precisely examined.

But we have now found that the false positive rate in samples like this where we do a pretty good preliminary vetting is about 90 to 95% true planets. Some features of this are that there is planets of - there's all - large planets appear in all the orbital periods that are shown on this chart.

But there's a big clump of planets that are between Neptune size and Earth size. So small planets are more common than large planets. The other - another feature is this only goes out to 400 days, by this time we had not collected enough data to be able to see enough transits in the longer period orbits to be able to identify transiting planets.
And also there is a sort of a blank area down in the lower right where the small planet size where we need more transits to surely identify transit signal and the longer periods means that we cannot probe that region very well in the 2011 data.

So go to the next slide, which is number 20 and I have added the candidates that we have produced from data collected between 2011 and 2012, another year of data.

And you can see that now we're starting to fill in that region in the lower right with longer periods, smaller size planets and the shorter periods we're detecting smaller planets yet because we see more transits and they've become more sensitive to them.

But other than that the overall distribution of planets is about the same. There's lots more planets that are between Neptune and Earth size than there are larger planets.

Next Slide 21, so as of January of this year we had collected 2700 odd planetary candidates and, you know, beginning to, you know, more filling in to the lower right and to the bottom of the smaller planets still the same general shape.

Now in July as shown on the next Slide Number 22 we put out our latest group of planetary candidates. These were detections that we had passed through our initial vetting procedures so that they were this, you know, 90 to 95% - (90 to 90%) true planets.

And so this is what the story looks like today, we have another 12 months of data that has not been well analyzed yet so we're going to get, you know, more planets yet out of longer periods and more candidates yet done for shorter periods but this is where it stands today.

The next slide is number 23 and I have taken the candidates on the previous graft and stacked them up in the (cystogram) so you can see how many planets of different sizes Kepler has seen.

Now so again as you expect the bulk of the planets are the Neptune size planets between two and six times the size of the Earth, many fewer Jupiter size and large super Jupiter size.

We believe the fall off in planetary occurrence rate to the large planets is real because we believe we've seen all the Jupiters, super Jupiters and Neptunes that are out there. Those signals are large enough that we can pick them up with high reliability right away.

The fall off on the side to smaller planets super Earths and Earth size planets is probably not as steep as it is shown in this plot because we know that we have detection problems.

We don't see all the planets of Earth size because they're hard to see they're low signal and noise. So a little later I'm going to show you a chart where we correct for this effect as best we can to get an idea of what the real frequency of planets are.

So let's go to the next Slide Number 24 and here I have re-plotted those candidates as of July and on a different scale. Because we know something about the stars that the planets are around and how much energy the stars emitting we can figure out what the temperature of the planet roughly would be for its orbital distance.
And I've now re-plotted these candidates with their equilibrium temperature versus their size relative to the Earth. And the equilibrium temperature is the temperature that a black atmosphereless rock would have orbiting at the same distance from its start that the planet is.

And over on the left hand side in that green band is what we believe is a sensible - a sensible habitable zone and I'll talk about why we picked those temperatures - temperature boundaries for he habitable zone in a minute.

When you look at the next Slide Number 25 where I've expanded the temperature scale to show only the habitable zone. These are equilibrium temperatures between 185 degrees Kelvin and 303 degrees Kelvin minus 126 Fahrenheit to 86 Fahrenheit.

Now you will immediately understand that those are not the boiling and freezing points of water. However, planetary science is to worry about the effects of atmospheres warming the surface of the planet over the equilibrium temperature that's the greenhouse effect.

Tell us that these are good limits to the habitable zone equilibrium temperatures if you expect the surface temperature of a planet with an atmosphere to be between the boiling point and the freezing point of water.

There are 102 habitable zone planets plotted on here. They're scattered all through with all different planet sizes except down toward Earth size where I mentioned before completeness is falling off because our sensitivity to small planets is not as good as it is for big planets.

But those are the ones we're looking for habitable zone planets that are Earth size sort of between 1 - between 1/2 an Earth diameter up to about 1 1/4 Earth diameters are Earth size and then super Earths go up to about we call up to about 2, 2-1/2 Earth diameters.

There's not so many down in that region but with the - with another year of data to analyze we hope to populate it more and there are a couple of good candidates, which are very close to earth size and in the habitable zone.

Now in the next set of slides, next two slides starting with number 26 I want to show you some of the confirmed planets that have come out of Kepler. These are the ones where we've not only taken the planetary candidate but we've examined it very closely and decide that there is less than a 1% chance that we're wrong about this being a real planet.

So Kepler 16b I should explain a little bit about how we name planets. The star, most of the target stars we look at don't have names except catalog numbers.

So when we confirm a planet around a star we give it a Kepler star number. In this case it would be Kepler 16 and the first planet that we confirm around that star we add a small letter b because the star itself is a the small letter a.

So the planetary name convention goes like that. So sort of the 16th star that Kepler 16 and Kepler 16b is a Saturn size planet. And it turns out that Kepler 16 is a binary star.

So this Saturn size planet just outside of the habitable zone in a 41-day orbit so this is - these are an M star and a K star pair is a star - is a planet sort of like Tatween from Starwars.

Where you would have double sunsets and double sunrises and two stars on the sky almost all the time. Because it's Saturns size and we expect it to be a gas giant we wouldn't expect the planet itself to have a habitable surface but if there were moons around the planet there's a good chance I like to think that one of those might be habitable.

The next Slide Number 27 shows a diagram of the Kepler 16 system. Now the stars are now labeled capital A and B because stars get capital letters where planets get little letters. And the orbit of Kepler 16B is shown relative to the size of the orbits of the stars.

In the next Slide Number 28 we have an artists conception of a possible sunset on a moon of Kepler 16B. And they didn't quite get the stars brightnesses the right ratio because one of them is an M star and one of them is a K star so one would be dimmer than the other by more than this shows.

But we now know of five more planets and three other well actually it's more six planets and four other systems because a new one was discovered last week within the circum binary configurations. So we believe that actually circum binary planets must be fairly common out in the galaxy.

Next slide shows Kepler 22b, which is in the habitable zone of a solar like star but it's 2-1/2 times the size of the Earth. The equilibrium temperature would be 14 degrees Fahrenheit with, you know, atmosphere warming it up to good habitability if its got one.

Now we have not been able to measure the mass of this planet yet because the planet mass is to small to easily do with the radial velocity method. So we haven't been able to determine its density.

We don't know whether it's a water planet or it has a rocky surface or a deep atmosphere. And at 2-1/2 times the size of the Earth is sort of on the border line where this might be changing from, you know, gas giant or ice giant planets to rocky planets.

We are beginning to get some statistics now with planets that we have been able to measure the density of and we believe that the transition region is somewhere between 2-1/2 times and maybe 1-1/2 times the size of the Earth.

So in several other examples I'm going to come up with here I'll say they're probably rocky and that means that they're in this transition zone that we're still exploring.

In the next Slide Number 30 is the Kepler 69 system where we have a fairly large Neptune size planet very close to the star quite hot but an Earth size planet at the inner edge of the habitable zone of Kepler 69.

Go to the next Slide 31 there are some statistics on this. Kepler 69c is 1.7 times the size of the Earth, equilibrium temperature of 80 degrees Fahrenheit, mass is unknown like I said but it's probably rocky. This might be a warm habitable planet, quite warm because without the atmosphere it would already be 80 degrees Fahrenheit.

Next slide is the Kepler 62 multiple planet system where there are five planets but two near Earth size both orbit in the habitable zone of this K2 dwarf, somewhat dimmer than the sun and these planets are shown in the next two Slides 33 and 34.

Kepler 62f is on 33 it's 1.4 times the size of the Earth. We tried to measure the mass but we only got an upper limit, mass is uncertain it's probably rocky. The next Slide Number 34 shows and let's see what was - yes Kepler 62f is a little on the chilly side but still in the habitable zone.

Kepler 62e is closer to the star with a 30 degree Fahrenheit equilibrium temperature 1.6 times the size of the Earth, composition probably rocky. This might be another Earth.

In the next slide starting with number 35 I want to talk about a pleasant surprise that we had with the Kepler survey. And that is we discovered lots and lots of planetary systems where the orbits are co-planar enough so that if one planet transits there's a high probability that other planets will transit.

This was an unexpected find we didn't know whether planets planetary systems were going to be flat enough to do this. And the good thing about this is it tells about the architecture of planetary systems not just the planets themselves. And also planets in multiple transiting systems tend to be self confirming because multiple occurrences of false positives is somewhat unlikely.

And the next Slide Number 36 I have plotted in the manner of the previous plots you've seen the multiple planet systems by color coding them with colors instead of just the white for the single planet systems.

You can see that multiple planets occur in at all periods and all sizes except there are no short period Jupiters in multiple systems that's in the upper left hand corner there, there's no colored dots up there.

So hot Jupiters are lonely and this is possibly because they've eaten all their brethren as they migrated in from distant parts of their planetary system up very close to the star. We don't know for sure that that's what's going on but that's one possible explanation.

The next Slide 37 gives some statistics of the multiple candidate systems basically there's more than 470 - more than 400 stars pushing 500 stars with more than 1200 - well more than 1100 planets in multiple systems.

And then the next few slides, the next three slides you should just browse through because they're in there to show you the configurations that we found in multiple planet systems, the planetary architectures that are out there.

In this first of the slides number 38 the solar system is shown on the extreme left with three little planets in near close to the star then two bit planets and then two medium size planets.

And for a long time all of our theories of planet formation were sort of predicated on making, you know, our planetary systems come out like that. But as you can see on this slide and the next two the multiple planet systems have all kinds of configurations.

Bit planets in close to the star, big planets far from the star, little planets close, little planets far and even big planets alternating with little planets. So this is one the really nice things we're getting out of Kepler

We can begin to analyze real planetary system architectures and figure out much better than we could before about how planets might actually form around stars.

So those were the slides up through Slide 40 so let me go to Slide 41 now, which is the Kepler census as of May of 2013. This is the sort of the bottom line that we're getting to here.

In May we had more than 2700 candidates around more than 2000 stars based on 22 months of analyzed data. Three hundred and fifty-one were Earth size, 58 were in the habitable zone and you can read the rest of this chart but the latest chart is the next one, which is based on this July 10 data where we've analyzed 36 months of data.

I've got more than 3200 candidates around almost 2500 stars, 540 of them are Earth size, 102 are in the habitable zone, 22% of them have more than one candidate planet around them and 17 candidates in the habitable zones of these candidates are less than twice the size of the Earth.

And one of them Kepler 69c is now confirmed in orbits of G type sun like star. So we're homing in on finding another Earth, another potential Earth. Now we now are not producing bulk deliveries of planetary candidates anymore.

Now the candidates are being added to the databases as they are found and you can go look at (exoplanetarchived@ipac.caltech.edu) that IRL - the net address to keep track of these things and the current score for confirmed Kepler planets is 135.

The next chart is the one I promised where I have corrected the - we I didn't do this, this is a Kepler team effort where we have corrected the actual observation frequency of planets to something that we believe is more like the actual occurrence rate.

And you can see that the corrected occurrence rate for Earths and super Earths are boosted up much closer to the small Neptune size planets than they were in the observation rate. And the fraction of stars that have at least one planet of these sizes is getting to be quite large, you know, 15%, 20% of stars have planets of these sizes.

The next slide, 44 summarizes this. One in six stars we believe has an Earth sized planet with a period less than 85 days, 70% of the stars have a planet of any size with a period less than 400 days and we haven't been able to include long period Earths and super Earths yet because our detection reliability isn't good enough.

So almost all sun like stars appear to have a planetary system. You go out tonight and look up at the sky and every star you see almost every star you see has a planetary system around it.

In the next Slide Number 45 we talk about results that we're getting for what kinds of planets appear around what kinds of stars. It was previously thought that small planets were more common around small stars but that's turning out not to be so much true.

The results of Kepler we can be best explained with planets of all different sizes approximately equally common around all different size stars at least within the M, G, K stars that Kepler has looked at.

The next Slide Number 46 reminds us that most of the stars are not sun size stars, sun mass stars but they're red dwarf stars, which are 10 times more common than solar stars in the solar neighborhood at least.

On the next Slide Number 47 shows that an analysis undertaken by (Courtney Dressing) at Harvard where she analyzed the 95 planet candidates in Kepler that are orbiting M type stars and she's come to the conclusion that at least 60% of these stars host a planet smaller than Neptune.

The next Slide Number 48 she's broken those 95 candidates down into the habitable zone and she finds three of them are in the habitable zone of M type stars. So 6% of M stars host planets smaller than 2-1/2 Earth radii in the habitable zone. These are the guys that could be, you know, habitable planets.

And the next slide summarizes this number 49, the nearest Earth size planet that's in the habitable zone could be as we say just a stroll across the park or only 13 light years away. This is beginning to be a distance where we can think about going there if we can find out which M star this is.

So that's my summary of the current Kepler results and the next Slide Number 50 summarizes the current Kepler status. As most of you have heard I'm sure there was a reaction wheel failure on Kepler several months ago.

Well there was one - the Kepler satellite is pointed with enough precision to do this precision photometry by what we call reaction wheels. These are things that are like gyroscopes but we don't use them like gyroscopes to keep the axis in the same direction.

We use them to spin up and spin down and move the telescope in the opposite direction from what we're - from how we're spinning the wheel. That allows us to keep the observatory pointed with great precision.

We started the mission with four of them. You need three to get full three axis control. More than a year ago one of them started misbehaving and we shut it down and we've been running on - had been running on three since then.

A few months ago one of those remaining three failed and stopped, stuck. So we were unable to continue the Kepler exoplanet survey under those conditions.

However we've been doing a lot of work since then to see if we could revive Kepler. We've enabled a new safe pointing state, which we call point rest, which is very fuel efficient and we expect to be able to last three to four years in this point rest state while we think about what we can do to revive Kepler.

So as it says here Kepler is not dead yet. All the science data on the spacecraft was retrieved and the last two years of data have yet to be thoroughly analyzed, the last year is almost unanalyzed and the next to the last year has undergone some analysis like I told you before.

So the analysis is going to continue and we expect many more planets and much more science to come from Kepler with the existing data. And our illusive Earth analog may still work in that data.

Now what we're doing to try to revive Kepler is on the next slide. As it - as I have put it here Kepler has three known cards to play. We can try to restart the recently dead wheel, we have done that now and it does spin.

It - we were able to discover that it spun in reverse and not so well forward to start with but I think it's - I'm pretty sure it's spinning in both directions now. And the previously dead wheel the one we shut down more than a year ago is also - will spin again.

However both of these wheels show much higher friction than the good wheels and we're not certain that their performance is good enough to use for precision pointing.

And even if it is - well if it is good enough to resume precision pointing we would probably do so but we don't have a clear idea how long that would last. So we may get some more lifetime out of the exoplanet survey but we wouldn't expect to get very much.

We're also working on implementing a two-wheel thruster hybrid pointing mode, which we would use hopefully if either, you know, we can't use the two dead wheels or when - if we can use them when it finally dies.

However the two-wheel thruster hybrid mode will probably not offer the same pointing stability as before so the old exoplanet survey probably would have to be exchanged for some other kind of science and we have to decide whether that science return was worth the cost of designing and implementing this two-wheel mode.

So that's the end of my talk and I guess I'll turn it back over to (Dave) to moderate any questions you guys might have.

(David Frosper): Thank you so much Dr. Gautier. Now we actually had one question - a couple questions submitted via email right before the talk. These are from (Keith Lower).

The first question is what technology is required to actually say visualize an extrasolar planet and if it's even possible from Earth?

Dr. Nick Gautier: It's possible what you need is a big telescope. It needs to be big to - it needs to be physically large to generate the special resolution necessary to separate the star from the planet.

And it also has to be capable of separating out the very bright starlight from the planet light, now the higher the special resolution the easier that is. There are a handful of planets that have already been imaged as, you know, unresolved dots using chronographic techniques to suppress the light of the star and let the light of the planet be visible.

These are all planets that are large distances from their stars. So we're not there in the habitable zone yet. Getting, you know, some kind of imaging - well getting an image of a star getting more than one pixel across a planet and a distant star takes a very large telescope diameter to get the special resolution.

But if your willing to separate out the light and not resolve the planet so you can do spectroscopy of the planet, discover what kind of atmosphere it has then the technology to do that for fairly, you know, planets that are fairly far separated from the star exist today and some of that can be done.

We'll need somewhat larger telescopes to do it for closer in planets but there are also spectroscopic techniques that take advantage of the transit of the planet and the occultation of the planet, which can occur on the other side of its orbit to take the difference between the star plus planet spectrum and the star spectrum to get the planet spectrum out.

So there are again a handful of planets that we've been able to measure something about the atmospheric constituents of, typically these are, you know, giant planets.

(David Frosper): Cool thank you, before we head on Operator if you could tell those good folks how to call in just to - we have time for a couple more questions. So and after that we'll need - I just also want to mention that combined with these new discoveries from Kepler us here at the Night Sky Network are actually updating all of our tool kits for - well not all but for the planet quest and in it was first released in 2005 but it definitely needed some updates.

So they will be coming to you later this summer with the updated materials and I'm sure you've all been talking about these exoplanets in classrooms and at the telescope net meetings.

So with that in mind are there any more questions from the audience?

Coordinator: If you would like to ask a question by phone please un-mute your line and press star 1, you will be prompted to record your name, which is used to introduce your question.

Again if you would like to ask a question at this time please press star 1, one moment for our first question. Our first question is from (Stewart Meyers), your line is open.

(Stewart Meyers): ...and on the current on the status of Kepler.

Dr. Nick Gautier: Yes.

(Stewart Meyers): And I'm wondering since it's a - since, you know, I mean the way things are looking for the Kepler mission are there any plans for any sort of a sequel to Kepler?

Dr. Nick Gautier: Yes, NASA has recently approved development of a project called TESS, transiting exoplanet, I've forgotten what it means but it's a Earth orbiting satellite, Kepler is in orbit around the sun, Earth orbiting satellite that scans the whole sky for transiting planets around brighter stars.

It's not going to be able to see Earth size planets very well because it's telescopes aren't large enough but it will get a good census of, you know, somewhat larger planets than Earth around all the nearby stars.

(Stewart Meyers): And I'm just wondering getting back to the issue with Kepler. Is there any speculation as to which of the message is the more likely?

Dr. Nick Gautier: Yes but the speculation is in both directions. Some people have some faith that we'll be able to get another, you know, three months or six months out of the reaction wheels.

Other people think that's highly unlikely and the first thing we should do is figure out how to do a two-wheel mission and then figure out if its worth paying for.

So my - I didn't give you a good answer to the question about which one we're going to do yet but we're going to find that out over the next few months.

Coordinator: Thank you our next question is from (Theo Retticus) your line is open.

(Theo Retticus): Great presentation Dr. Gautier. I have a question on the I think it was Slide 16 where you mentioned the CCD size for each of the segments of the field of view.

Dr. Nick Gautier: Yes.

(Theo Retticus): I thought you said 1K CCD, I presume that is maybe 1K CCD chips per sector or...

Dr. Nick Gautier: Well let me explain that again.

(Theo Retticus): Okay.

Dr. Nick Gautier: If you're looking at Slide 16 you'll see that there are 21 sort of square shaped things and each square is divided into two rectangles.

(Theo Retticus): Yes.

Dr. Nick Gautier: Each one of those rectangles is a 2K by 1K CCD.

(Theo Retticus): A 2K by 1K CCD okay now I understand thank you.

(David Frosper): I think we have time for one more question.

Coordinator: Just one second for our next question and that question is from (Victor Grossi) sir your line is open.

(Victor Grossi): Well thank you very much for a very interesting presentation. Could you - do you have any idea how many planet candidates in the habitable zone are within 40 or 50 light years?

Dr. Nick Gautier: Yes it's going to be that set of M stars almost exclusively because the other candidate stars that we looked at are to bright to look at within close distances. But outside of those M stars plus some habitable zone candidates, which might be around K stars I can't give you a list.

However if you go to the exoplanetarchive.caltech. whatever that address, Web address was you can get the complete list of planetary candidates with their stellar types and the brightnesses of the star and back out the distance yourself. Unfortunately I can't give you an answer off the top of my head.

(Victor Grossi): Okay thank you.

Coordinator: And there are no other questions on the phone line at this time.

(David Frosper): All right perfect that's all the time we have for this evening. Dr. Gautier thank you so much for your time and your excellent presentation and...

Dr. Nick Gautier: You're welcome I was glad to be able to do it.

(David Frosper): ...we wish you - awesome it was our pleasure to help you. So we wish you much future success and good luck with the Kepler revival however it happens and thanks again.

END